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Global Simulation of Electron Cyclotron Harmonic Wave Instability in a Storm-time Magnetosphere

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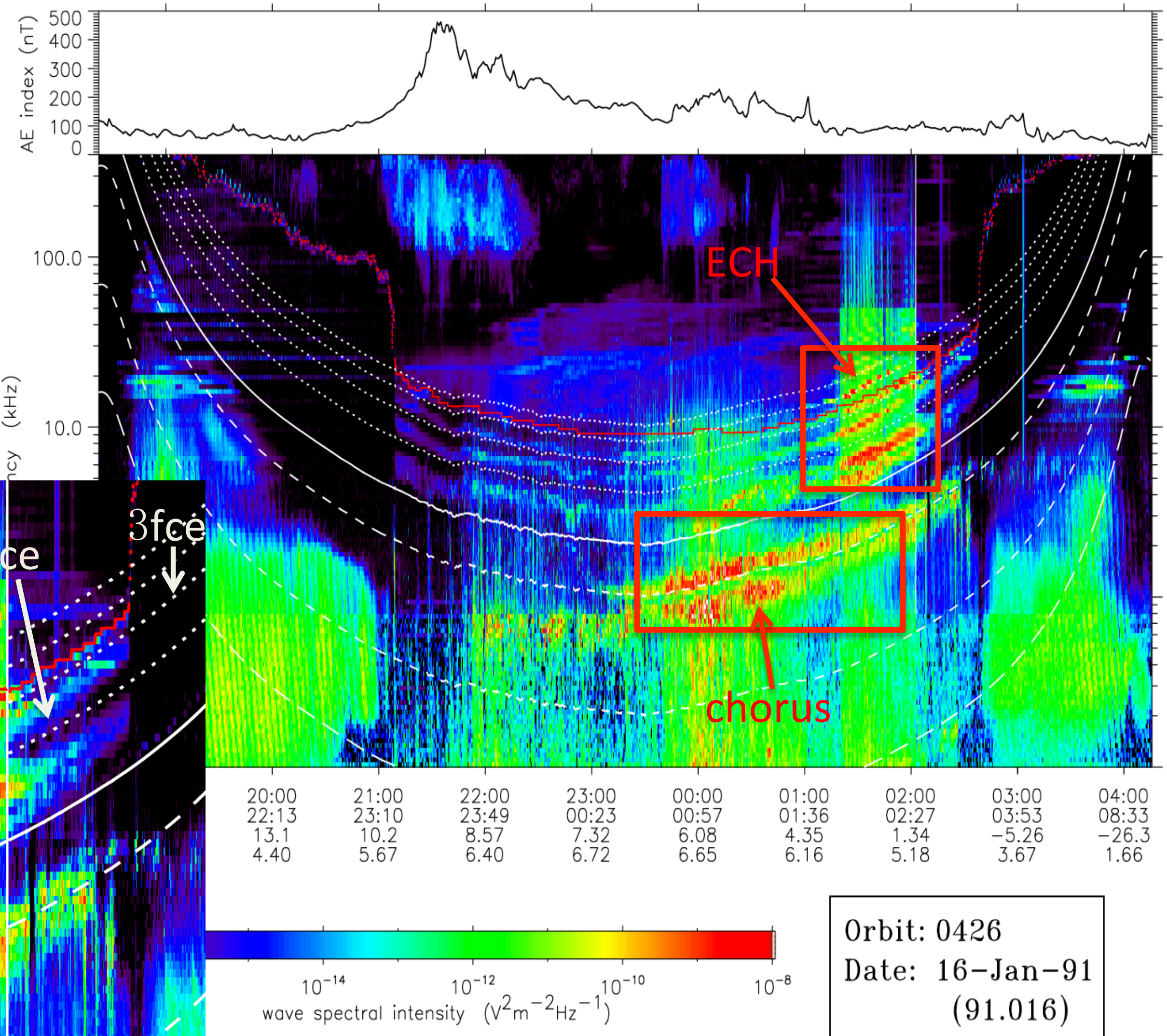
07/26/2018

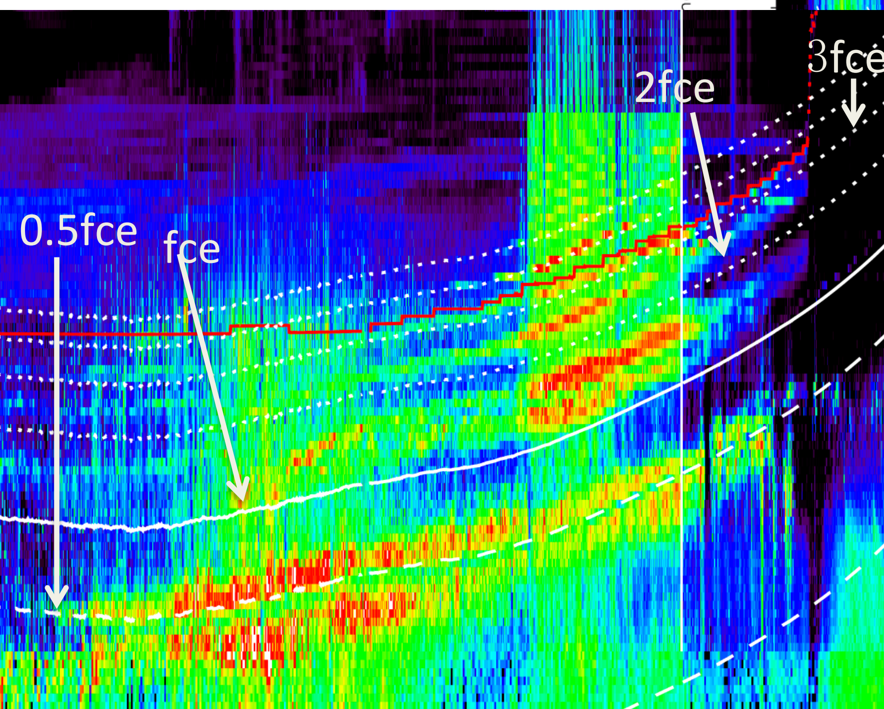
Introduction： ECH

Wave properties:

electrostatic emission with wave frequency between the harmonics of electron cyclotron frequency



ECH, chorus zoom in

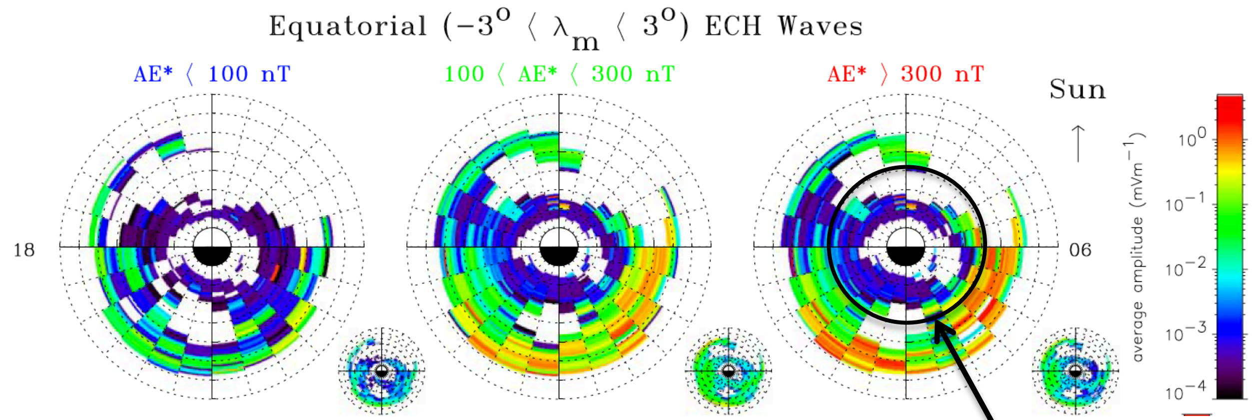


Introduction： ECH

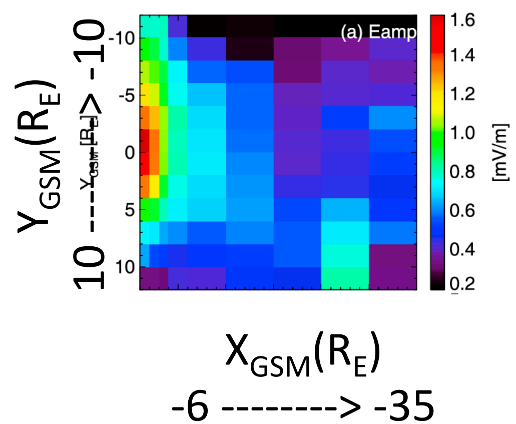
Wave properties:

electrostatic emission with wave frequency between the harmonics of electron cyclotron frequency

at the nightside within ~ 6 degrees of the magnetic equator over 4<L<10 (~ mV/m) [Meredith et al., 209; Ni et al., 2011, 2017] and extended L~35 in the magnetotail region (~ tenth mV/m) [Zhang et al., 2015]



Meredith et al., 2009



ECH magnitude

Zhang et al., 2015

- MLT dependence
- L dependence
- Geo-activity dependence

UT DALLAS

Introduction: ECH

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at the nightside within ~ 6 degrees of the magnetic equator over 4<L<10 (~ mV/m) [Meredith et al., 209; Ni et al., 2011, 2017] and extended L~35 in the magnetotail region (~ tenth mV/m) [Zhang et al., 2015]

Excitation:

Loss cone distribution [Ashour-Abdalla and Kennel, 1978]

Fast flow-driven dipolarization and electron injection from the magnetotail [Liang et al., 2011]

Question:

How to explain the observation?

- MLT dependence
- L dependence
- Geo-activity dependence

Local excitation

Propagation

Hot Ray tracing

Linear growth rate

UT DALLAS

Method : linear growth rate

Hot plasma dispersion relation for electrostatic mode

PSD → wave frequency and linear growth rate

$$D(\omega) = 1 + \sum_s \sum_n \frac{\omega_{ps}^2}{k^2} \int d^3v \frac{J_n^2(\frac{k_\perp v_\perp}{\Omega_s})}{\omega - k_\parallel v_\parallel - n\Omega_s} \left(\frac{n\Omega_s}{v_\perp} \frac{\partial f_s}{\partial v_\perp} + k_\parallel \frac{\partial f_s}{\partial v_\parallel} \right) = 0$$

Simplify phase space density

$$f_s = f_{s0} + f_{s1}$$

bi−Maxwellians

Tenuous and arbitrary

$\omega = \omega_0+\omega_1$

complex wave frequency

Wave frequency and linear growth rate

$$D_0(\omega_0) = 1 + \sum_n \sum_s \sum_j 2\frac{\omega_{ps}^2}{k^2} e^{-\lambda_{s,j}} I_n(\lambda_{s,j}) \left(\left(\frac{n\Omega_s}{k_\parallel \, a_{s,\parallel j} \, a_{s,\perp j}^2} + \frac{z_{s,nj}}{a_{s,\parallel j}^2}\right) Z(z_{s,nj}) + \frac{1}{a_{s,\parallel j}^2} \right) = 0$$

$$\omega_i \approx \omega_{0i} + Re\left[-\frac{Im[D_1(\omega_{0r})]}{\frac{\partial D_0}{\partial \omega}|_{\omega=\omega_0}} \right] \qquad Im[D_1(\omega_{0r})] = -\sum_s \sum_n \frac{\omega_{ps}^2}{k^2} \int_0^\infty 2\pi^2 v_\perp dv_\perp \frac{J_n^2}{|k_\parallel|} \left(\frac{n\Omega_s}{v_\perp} \frac{\partial f_{s1}}{\partial v_\perp} + k_\parallel \frac{\partial f_{s1}}{\partial v_\parallel} \right) \Big|_{v_\parallel = \frac{\omega_{0r} - n\Omega_s}{k_\parallel}}$$

$$f_{s0} = \sum_j \frac{N_{s,j}}{\pi^{3/2} a_{s,\perp j}^2 a_{s,\parallel j}} \, exp\left(-\frac{(v_\parallel - v_{s,dj})^2}{a_{s,\parallel j}^2} \right) \, exp\left(-\frac{v_\perp^2}{a_{s,\perp j}^2} \right)$$

Wave frequency: $Re[\omega_0]$

Linear growth rate: ω_i

$\omega_i > 0$: wave growth

$\omega_i < 0$: wave damped

Method: RAM-SCB model

RAM-SCB model

Global energetic electron

- MLT: 0 to 24
- L: 2 to 6.6
- Energy: 120 eV to 426.65 keV
- Pitch angle: 0 to 180 deg
- Time dependent

Ring current-atmosphere interactions model (RAM)

[Jordanova et al., 1994, 2006, 2016]

- Kinetic equation for H^+, O^+, and He^+ ions and electrons
- Including all major loss processes
- Convection and corotation E-field (supplied)
- Updated to general B field
- Coupled with a plasmasphere model

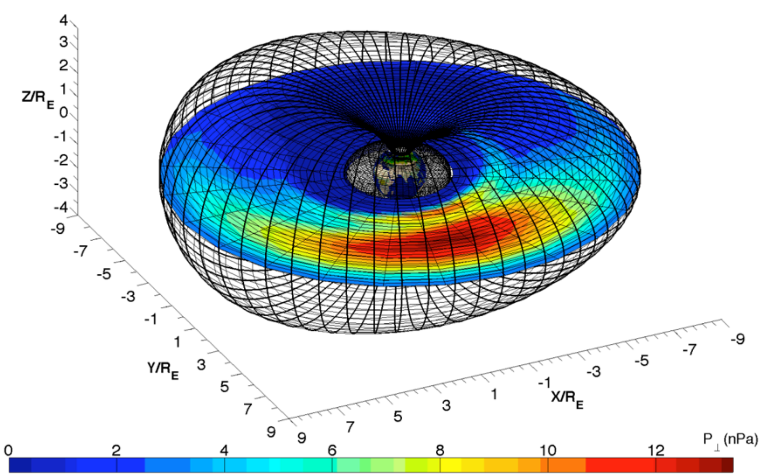
Pressure

B-field

3D magnetic field model

[Cheng, 1995; Zaharia et al., 2004; 2010]

$$\mathbf{J} \times \mathbf{B} - \nabla \cdot \mathbf{P} = 0$$



- B-field boundary conditions from empirical or other global models

Method： Step

1. Finding energetic electron phase space density from RAM-SCB model

2. Fitting energetic electron phase space density to find f_{s0} and f_{s1}

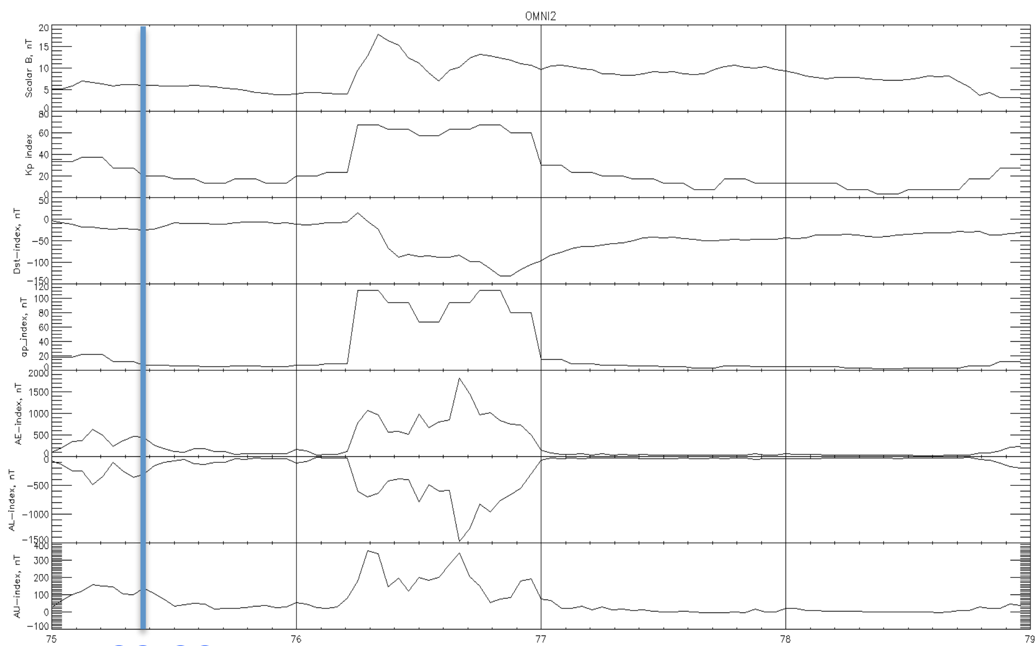
$$f_s = f_{s0} + f_{s1}$$

3. Using linear growth rate formula to find wave frequency and linear growth rate

Simulation period

2013/03/16 to 2013/03/19
(a big Geo-storm)

Solar B, nT
Kp
Dst
Ap
AE
AL
AU



Day: 16 09:00 17 18 19

Example

Phase space density

2013/03/16 09:00:00

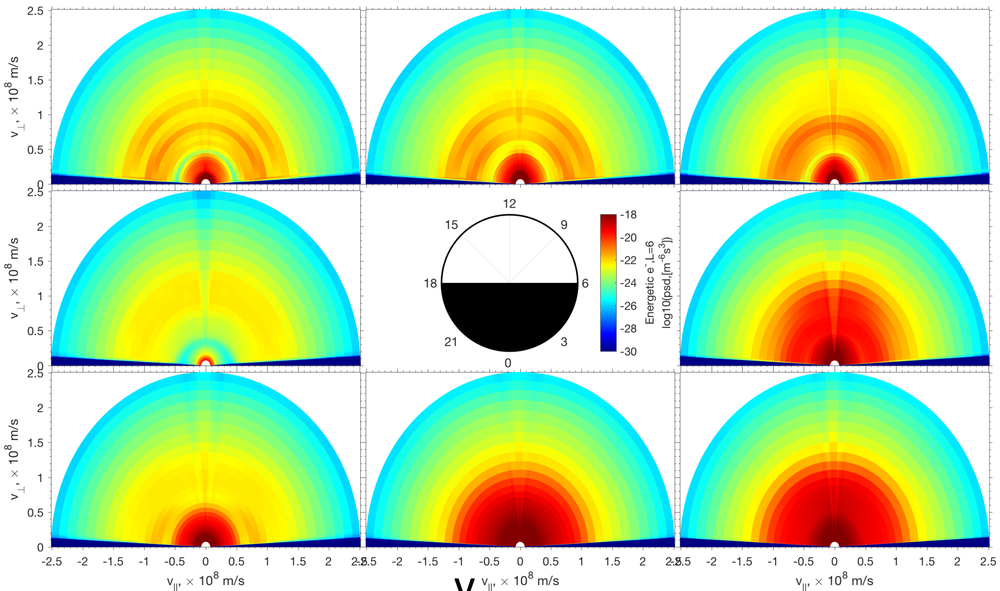
L=6

f=PSD from RAM-SCB

Step 1

dusk

v_{perp}



dawn

$v_{parallel}$

f_0=PSD from Bi-Maxwellians

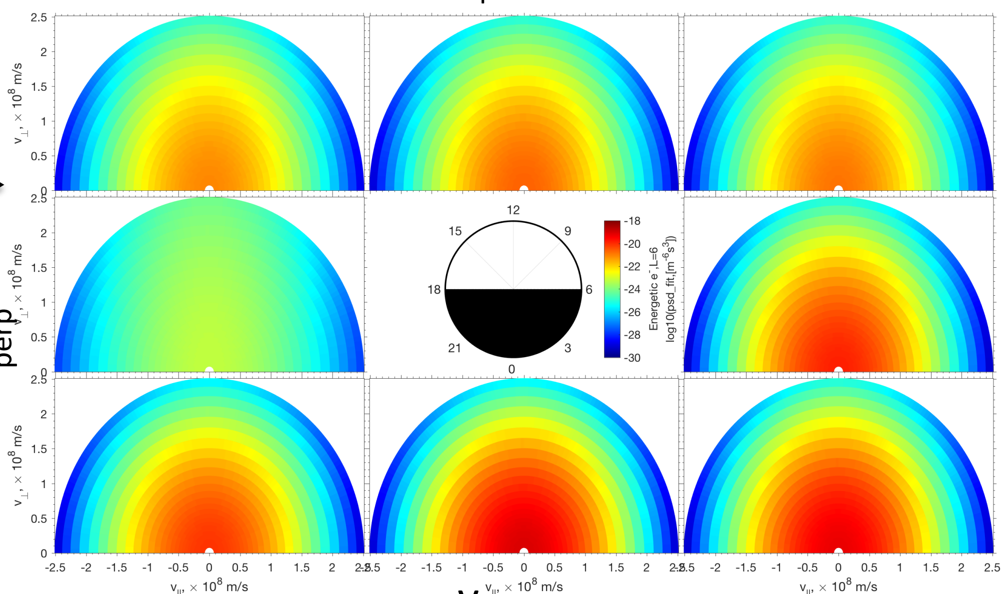
Step 2

dusk

f_1=f-f_0

Cold electron: 1 eV, isotropic

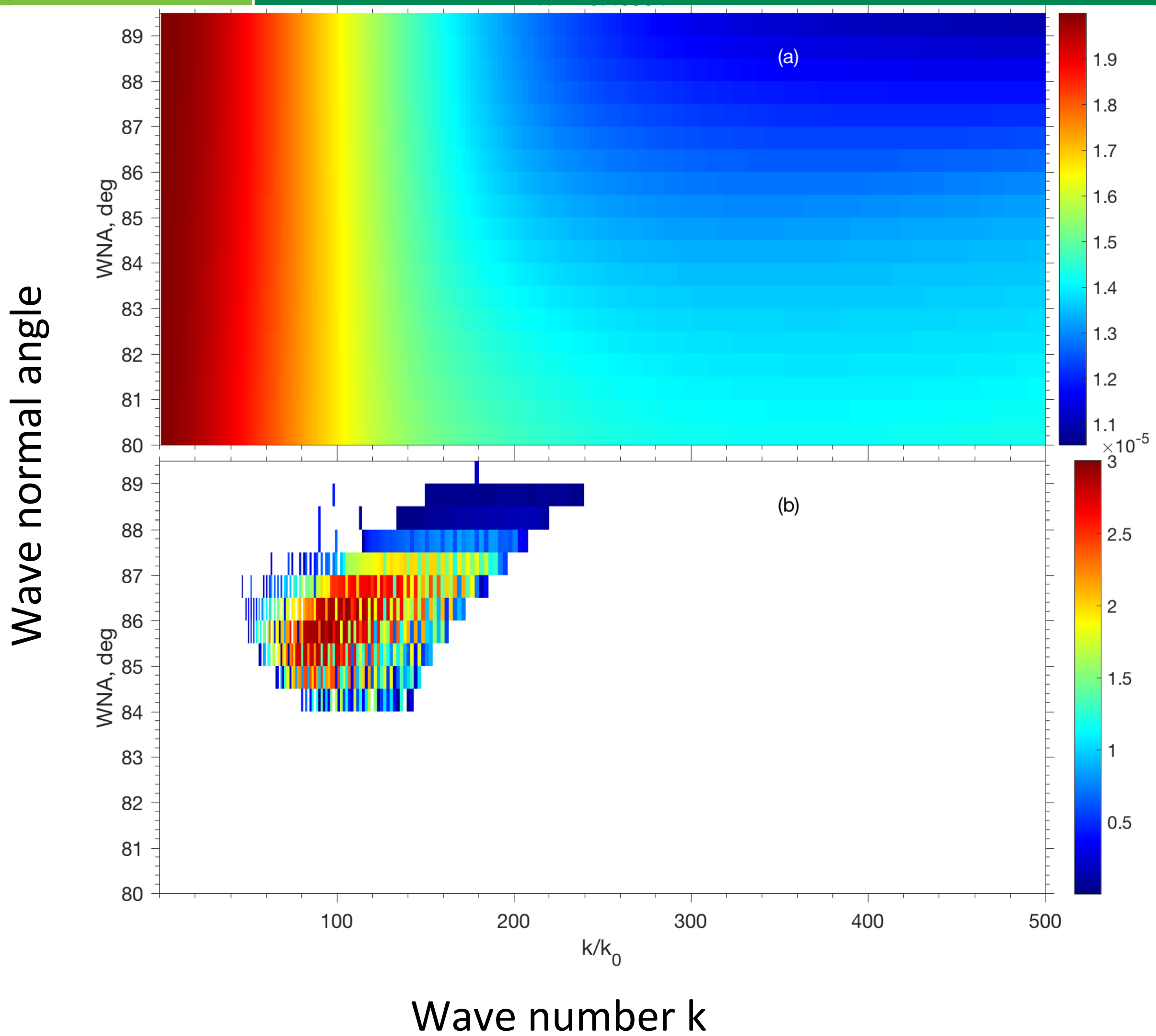
v_{perp}



dawn

$v_{parallel}$

Example



Step 3

Wave frequency

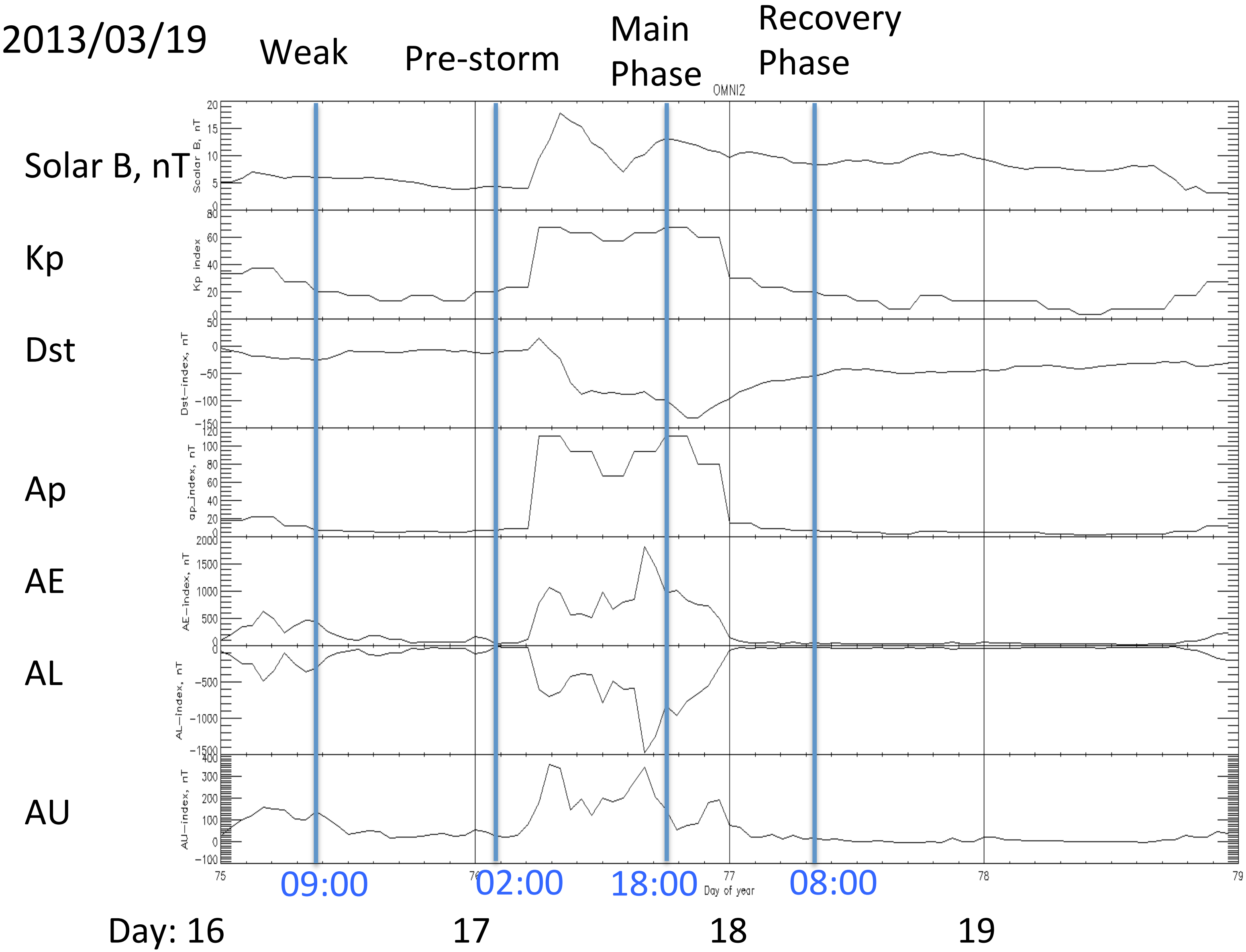
Linear growth rate

Compare linear growth rate values for different MLT, L and Geo-activity

Events

2013/03/16 to 2013/03/19
(GEM event)

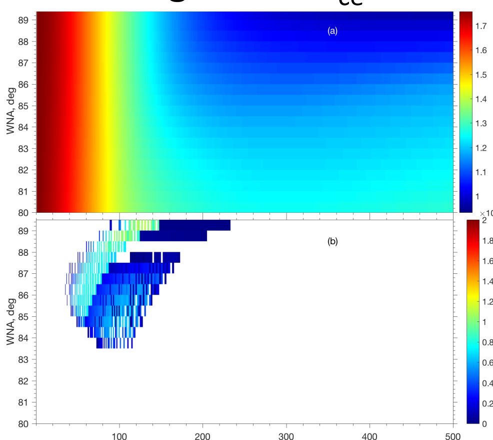
- MLT dependence
- L dependence
- Geo-activity dependence



MLT effect (Main Phase,L=5)

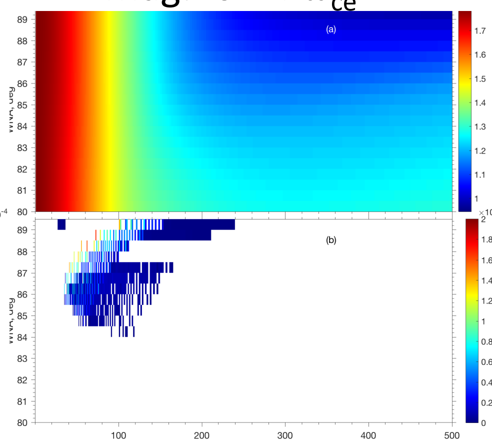
MLT: 0

Mag:10^-4 ω_{ce}



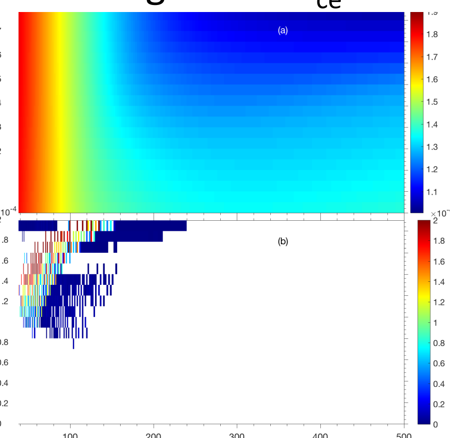
MLT: 3

Mag:10^-4 ω_{ce}



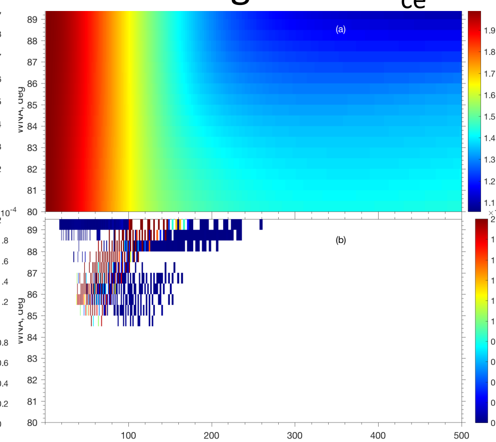
MLT: 6

Mag:10^-4 ω_{ce}



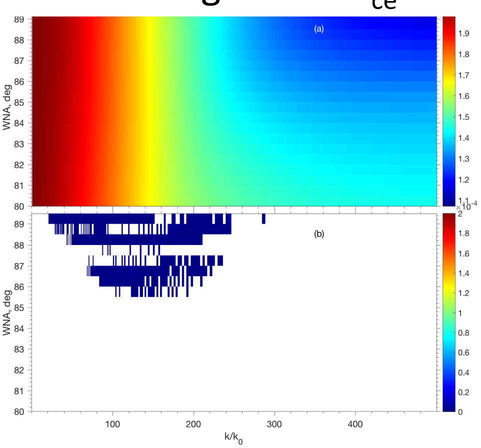
MLT: 9

Mag:10^-3 ω_{ce}



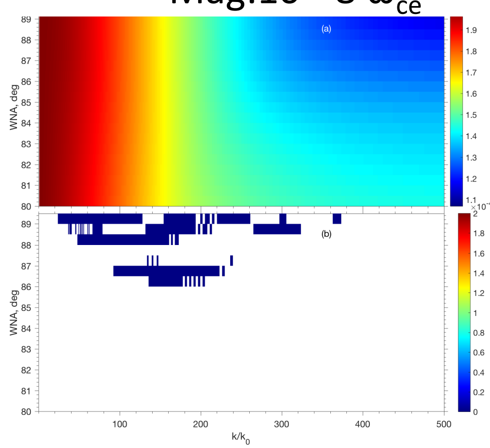
MLT: 12

Mag:10^-6 ω_{ce}



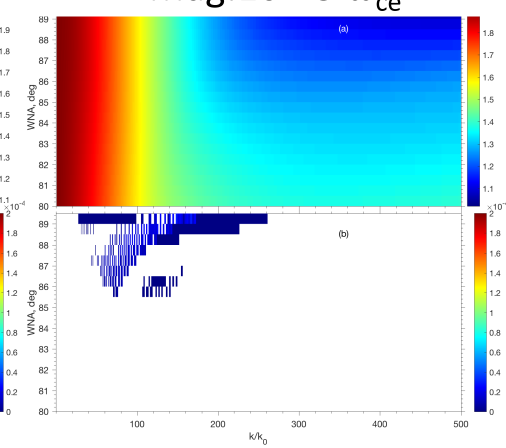
MLT: 15

Mag:10^-8 ω_{ce}



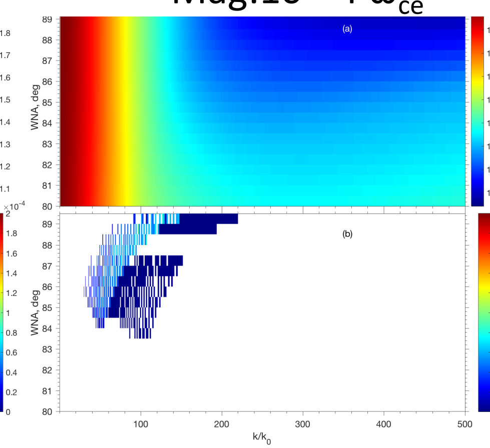
MLT: 18

Mag:10^-5 ω_{ce}



MLT: 21

Mag:10^-4 ω_{ce}

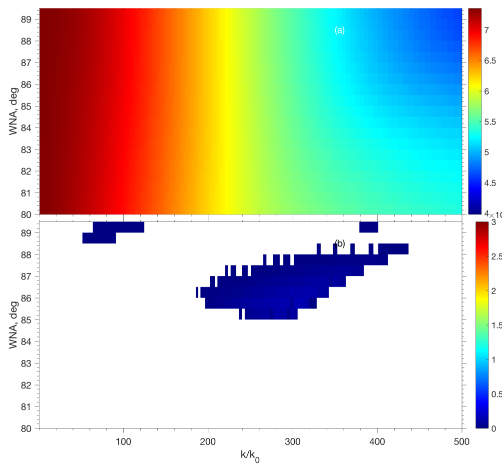


Instability is strong at nightside and dawnside, and is weak at dayside and duskside

L effect (weak activity)

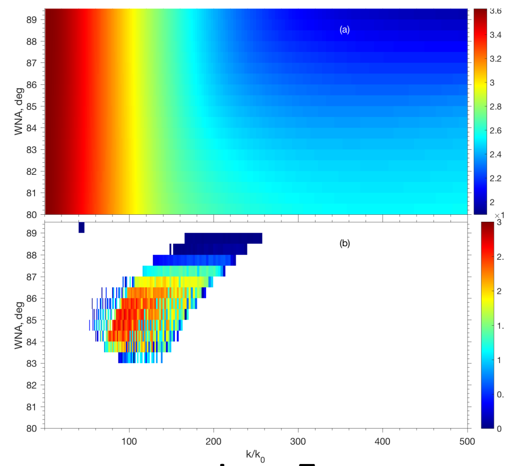
L = 4

Mag:10^-6 ω_{ce}



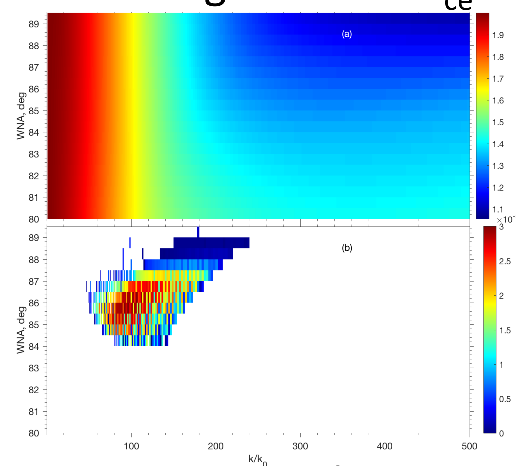
L = 5

Mag:2.5*10^-5 ω_{ce}



L = 6

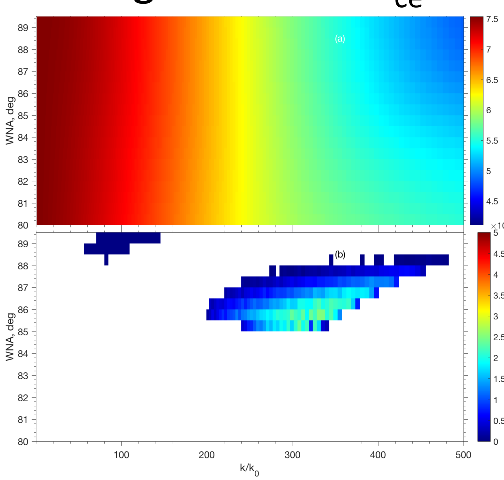
Mag:3*10^-5 ω_{ce}



MLT=0

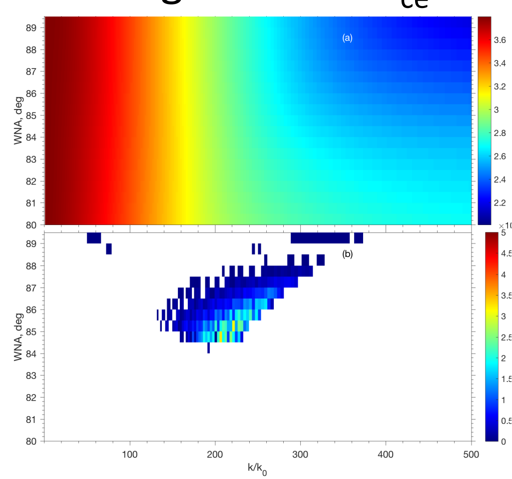
L = 4

Mag : 2*10^-6 ω_{ce}



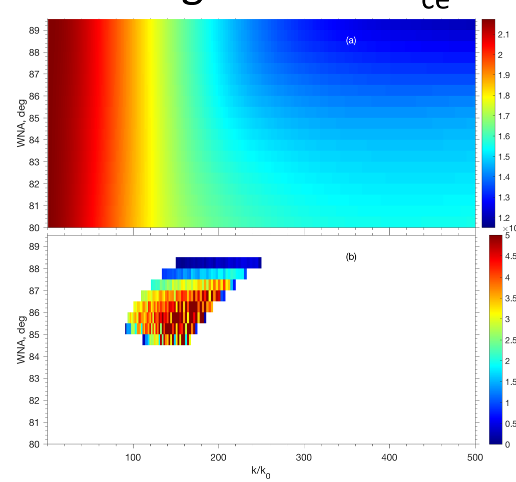
L = 5

Mag:3*10^-6 ω_{ce}



L = 6

Mag:7*10^-6 ω_{ce}



MLT=6

Instability is weak for small L

Geo-activity effect

Linear growth rate comparison for different geo-activity

MLT=0 : Main > Recovery > Weak > Pre-storm

MLT=3 : Main > Weak > Pre-storm > Recovery

MLT=6 : Main > Weak > Pre-storm > Recovery

MLT=9 : Main > Weak > Pre-storm > Recovery

Main Phase > Weak activity > Pre-storm > Recovery Phase

averaged AE of previous 3 hours: 1416 > 418 > 113 > 47

Instability is stronger for larger AE index

Conclusion

The global linear growth rate of Electron Cyclotron Harmonic (ECH) wave is evaluated for a selected geo-storm event by applying RAM-SCB model to the ECH linear growth rate formula. We find :

- Linear growth rate of ECH wave is strong at nightside and dawnside, and is weak at dayside and duskside.
- Linear growth rate of ECH wave is strong when L>4 and is weak when L<4
- Linear growth rate of ECH wave is strong for strong geo-activities

- All the instability analyses are consistent with the observation for ECH waves

2nd band ECH has similar results